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GROUND WATER

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DEPARTMENT OF INTERNAL AFFAIRS

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TOPOGRAPHIC AND GEOLOGIC SURVEY

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1958

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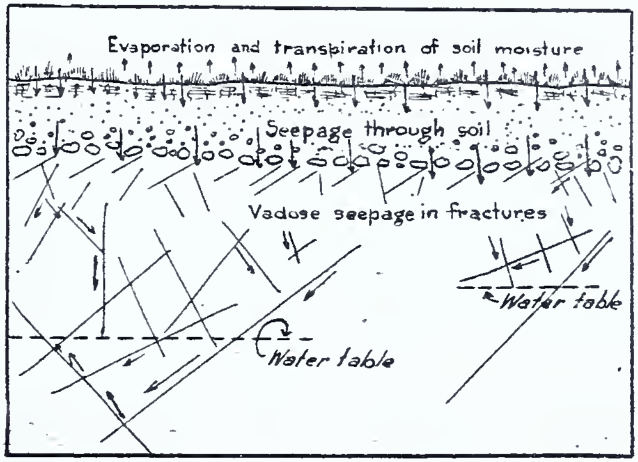
GROUND WATER

INTRODUCTION

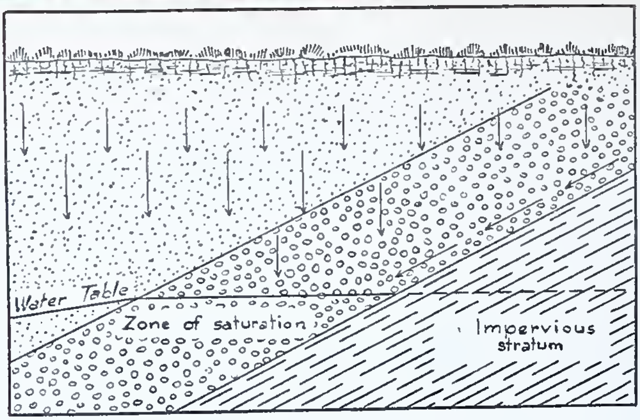
Underground water, because it is not visible, is commonly believed to travel in mysterious underground rivers, or emerge from the bowels of the earth in extraordinary domes and then radiate outward in veins. This is not the case. Actually, the principles of groundwater occurrence and movement are logical and well known, but as in the other branches of the earth sciences, details of occurrence and specific information are often a matter of interpretation.

OCCURRENCE AND MOVEMENT

Water moves through rocks in cracks, crevices, and small interconnected pore-spaces between the grains. Limestone, shale, granite, and fine-grained sandstone commonly have extremely small pores, or for all practical purposes non-porous. Water must move through such rocks in cracks or through channelways dissolved out of the rock by the water itself. Sand and coarse-grained sandstone often have larger, interconnected pore-spaces, and therefore transmit water throughout the entire rock, rather than in discrete channels.



The difference in the manner in which water travels through porous and non-porous rocks may be illustrated by analogy to a sponge and a block of rubber of identical size and shape, but the rubber having one hole, or channel, through it. The sponge is like a porous rock; water moves through its entire volume. In the rubber, all of the water moves through the one hole, as in limestone or shale.



A well in the sponge will produce some water whatever its location, while a well in the rubber must intersect the channel.

Following this analogy, when a water well is drilled in limestone, it must intersect one or more crevices in order to produce water. Such crevices or channels, may be a fraction of an inch or many feet wide, and the amount of water obtained depends in part on the number and size of the channelways encountered. In sandstones, the well must cut many pores to receive large amounts of water, since each pore may be only a small fraction of an inch wide

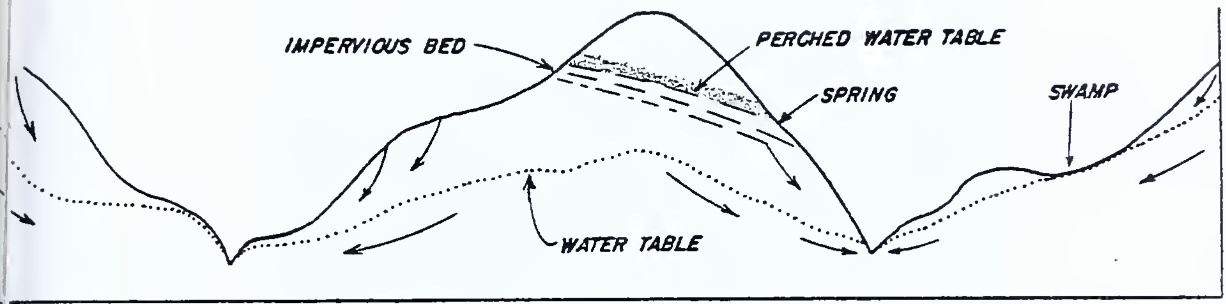
An aquifer is a rock unit from which water may be recovered through a well. An aquifer may be nearly any type of rock; a previous paragraph stated that any rock can carry water if it is sufficiently porous, or if other suitable openings, such as crevices or cracks are present. In actuality, most good aquifers are sands, gravels, sandstones, or limestones.

WATER TABLE

One of the basic concepts in groundwater geology is that of the water table--i.e., the surface below which the rocks are saturated. When the water in an aquifer is able to rise upward freely within the rock, watertable condition prevail, and water does not immediately rise above the level at which it was encountered in a well. The water table is not flat. Rather, it follows the gener contour of the surface of the earth; under hills the elevation of the water table is higher than beneath valleys. The depth to the water table may vary from zer to many hundreds of feet, depending upon the climate and geology of the area.

The water table is usually at or near the surface in valleys occupied by major stream. At other intersections of the water table with the surface swam or springs will exist depending on local conditions. Ignoring the influences of beds of non-porous rocks the movement of water beneath the groundwater table toward and along the major surface drainage features.

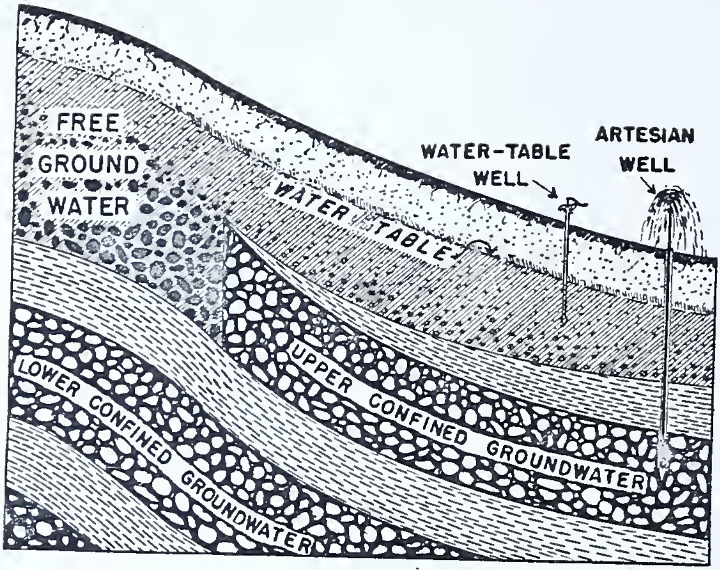
The diagram illustrates the general rule that wells on a hill must be eeper than those in a valley. It also shows one of the several exceptions. A erched water table is merely a water table controlled by an underlying impervious ed. Beneath the impervious bed, however, the rocks are not saturated until he general water table is reached.



ARTESIAN WATER

An artesian aquifer, is one in which the water is confined within the aquifer by an impervious bed. An artesian well is a well in which the water level rises above the level at which it was encountered. The "normal" artesian condition is found when an aquifer is bounded at the top and bottom by impervious beds such as a clay or shale. A favorable locality is usually in a structural basin, or syncline, where the aquifer lies at a lower elevation than at its outcrop in the surrounding areas.

The situation is somewhat like the water distribution system of a city having a reservoir in the hills. The aquifer acts as the opening in the main, the confining bed acts as the walls of the main, and the outcrop of the aquifer acts as the reservoir, collecting water from rainfall for storage. An artesian well is like a water pipe in a tall building in that it taps an aquifer (the main) which contains water under confining pressure. This confining pressure causes water to be ejected from the aquifer, and rise into the well (water pipe). Artesian wells may or may not flow water out upon the surface; the definition calls only for water to rise above the aquifer. Only under artesian conditions can water from a well be considered to have traveled any considerable distance. Whereas under watertable conditions, water is derived from the immediate vicinity of the well, artesian water may have entered the aquifer as much as tens of miles or more away from the well.



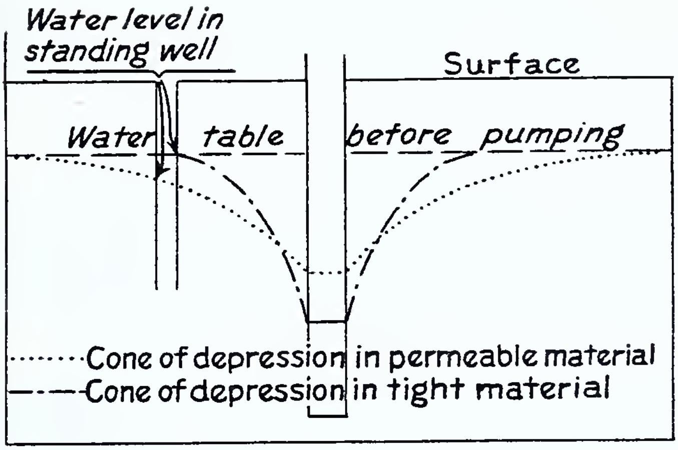
QUALITY OF GROUND WATER

With the increased demands upon ground water in industry, dissolved mineral content of water is becoming even a greater problem than quantity of supply. Technical methods of investigation are also becoming more and more important.

Most well water is derived from rain which has soaked into the earth and seeped through the rocks to the well. As it travels through the rock, it dissolves some mineral matter from the rocks and carries it along in solution. In the areas underlain by limestone, the water will invariably carry a heavy load of dissolved calcium carbonate derived from the limestone and be "hard". In most sandstones, calcium carbonate is not a great problem; iron or mangane are sometimes encountered, very small amounts of which may be detrimental. In black shales or coal, the water may be charged with hydrogen sulphide gas (smells like rotten eggs) or sulphates, and be very corrosive as well as unpotab.

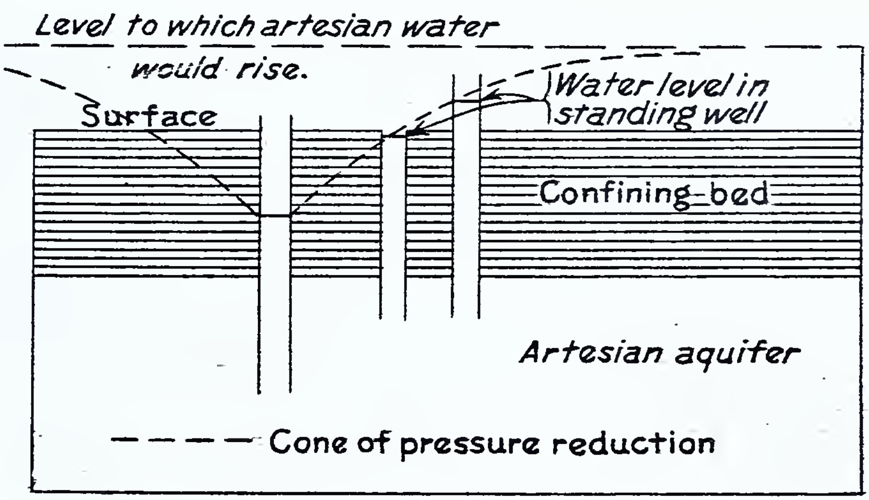
Salt in ground water may be derived from ancient or modern seas, or from dissolved rock salt. Only ancient sea water, trapped in the pores of the rock when the rock was formed, is a problem in Pennsylvania. In the western part of the State, deep wells may tap formations which have not been flushed with fresh water and the water will be salty.

Scientific methods of groundwater study have proved to be of invaluable aid in predicting the quality of water to be expected from a well, and the amount of water which may be withdrawn from a well without mineral pollution from near-by high-mineral water.



Pumping a well which taps the water table produces a "cone of depression", or cone-shaped, water-free area around the well. In very permeable material, where water may move with relative ease, this cone is broad and shallow; in tight or impervious material, the cone is steeper and smaller in areal extent. In other words, a well in gravel will lower the water table in a much wider area than one producing from sandstone or shale, but the depth of the cone, or "draw-down", will be much less. The draw-down and cone of depression are important in an understanding of the behavior of a water well as the most efficient pumping rate and interference between wells are directly tied to these phenomena.

In an artesian aquifer, there is no actual cone of depression (de-watering) but there is a reduction of pressure which may be visualized as a cone. Whereas the cone of depression of wells under watertable conditions spreads rather slowly to affect the surrounding area, the pressure reduction in an artesian aquifer is almost immediate.



The preceeding diagrams show wells which tap the water table and an artesian aquifer. Each is pumping, and the corresponding draw-down and cones of depression and pressure reduction are shown. The area affected by a cone of depression on the surface is circular in shape. Therefore wells anywhere within the radius of the cone will be directly affected by the amount of water withdrawn from the pumping well. Properly performed and interpreted pumping tests can indicate the most efficient pumping rate and well spacing for a given aquifer.

PROSPECTING FOR WATER

First, it must be determined what type of rock is involved in the possible well sites. For the purpose of this discussion, rocks may be divided into two general classes, those which contain unconfined water (watertable conditions), and those having confined water conditions (artesian). We shall first consider areas where unconfined water will usually be encountered.

Shales, unconsolidated sediments, and metamorphic and igneous rocks usually contain water under unconfined conditions; the water is not confined within a certain bed, but can rise or decline freely according to the availability. The water occurs in small cracks, fractures, and spaces between grains within the rock. Under these conditions, free water usually occurs near the surface of the earth where the fractures in the rocks are more likely to be open. This is another way of saying that the water table, or top of the zone of saturation, generally follows the surface contours of the ground. A good location for a well in such rocks is one in which there are a large number of fractures, and which has a sufficiently large reservoir or catchment area. The most favorable location is usually in a stream valley or near a valley head where several small streams converge. Such a location is desirable for several reasons. First, the water table will probably be nearer the surface in a valley than on higher ground. This is important because the thickness of the zone from which water is obtained is a critical factor in a well. Second, valleys form more easily in an area where the rock has been more intensely fractured and therefore one could expect more fractures in a valley; they are often large due to increased solution. Third, the water table will slope toward the well from upstream and from both sides, giving a greater area from which to obtain water. Last, but not least, the stream itself may continuously recharge the water table in the valley. A well located on the top of a hill which is underlain by shales can be expected to encounter fewer fractures, and to tap a high point on the water table so that there is no large area to catch precipitation, and no streams which could recharge the groundwater system. It must be remembered that unconfined water does not travel long distances; it is derived from precipitation in the near vicinity of the well.

As fractures are, in general, in the weathered zone of rocks, wells in shales and metamorphic and igneous rocks, are usually limited to about 300 feet. The depth of wells in unconsolidated sediments depends on local geology.

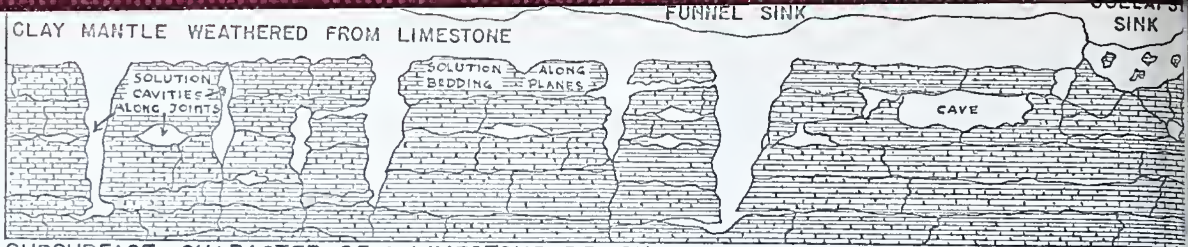
In an area in which permeable beds, such as sandstones, alternate with impermeable beds such as shales, the sandstones are commonly artesian aquifers. By mapping the outcrops and attitudes (dips) of the rocks, one can predict how far below the surface an artesian aquifer lies in a given locality. Thus, if a sandstone is known to be a good aquifer (such as the Connoquenessing sandstone in western Pennsylvania), a well can be located at a point at which it will tap the Connoquenessing at a depth which will assure a sufficiently large drainage area. Whereas it is usually uneconomical to drill for unconfined water below 300 feet, confined water wells are often several times that deep, as a definite formation or bed is being sought.

Faults (zones along which the rocks have been broken and moved) are another good source of confined water. Here again, geologic mapping of the surface rocks is necessary to determine the position of the fault, both on the surface and underground. From such geologic mapping one may learn where to locate a well that will penetrate the fault zone at a reasonable depth.

For confined-water wells of these types, a particular formation, bed, or fault plane is sought. In order to locate such wells intelligently, reliable geologic maps must be available. Fully one-half of the State, including large areas in which surface waters are unpotable, is underlain by alternating permeable and impermeable beds. The part of the State in which other types of rock predominate is marked by many faults. One of the important applications of detailed mapping of geology can be recognized in the study of ground water in Pennsylvania.

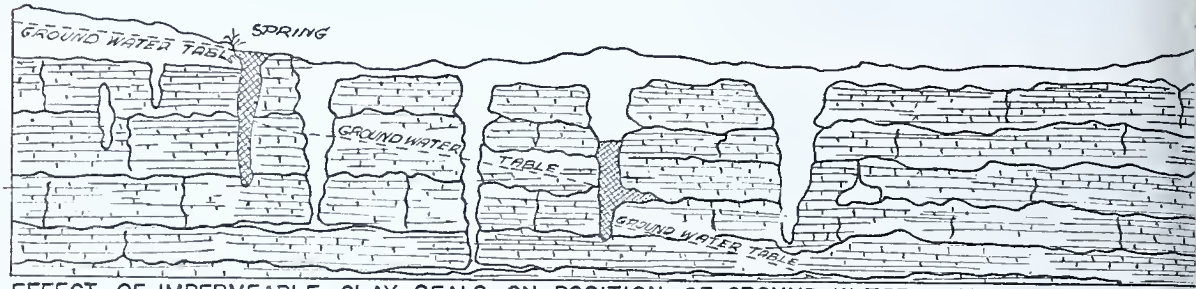
Limestones as a source of ground water were not included in the preceeding paragraph of the discussion of water wells which tap confined water. Most limestones are non-porous and carry water only in fractures and solution channels. Since the water in these openings cannot move freely into the surrounding rock, it also must be considered as confined water, and may or may not be artesian.

Limestone differs from other non-porous rocks, such as granite, in that it can be appreciably dissolved by ground water. Rain, the ultimate source of most of our ground water, contains carbon dioxide derived from the air. Such a solution of carbon dioxide and water is a weak acid and when it moves along fractures and other openings in limestone, it dissolves the rock, enlarging the openings. The process is slow, but geologic time is almost unbelievably long. By this process all limestone caves, including the tremendous halls of Mammoth Cave and Carlsbad Caverns, were formed. Whereas solution openings in limestone are known to depths of over 1,000 feet in Pennsylvania; the greatest concentrations of openings are relatively near the surface. Here circulation is faster and the supply of carbon-dioxide-rich water is replenished more frequently. The network of solution channels frequently becomes so effective that surface drainage all but disappears. Sink holes, disappearing or "sinking" streams, and caves, are signs of good development of underground drainage systems.



SUBSURFACE CHARACTER OF A LIMESTONE REGION

GENERALIZED SECTIO



EFFECT OF IMPERMEABLE CLAY SEALS ON POSITION OF GROUND WATER LEVEL

IDEALIZED DIAGRAMS OF LIMESTONE AND GROUND-WATER CONDITIONS.

To obtain water in limestone terrain, a well must intersect one or more water-bearing openings. As these openings often are small pipe-like affairs, and are invisible from the surface, making a well location is something of a hit or miss proposition. The chances of success can be improved by choosing a site having the surface indications of good underground drainage just mentioned. Sink holes, swales, and dry valleys are depressions formed by the dissolving a of the underlying rock by ground water. Solution openings are naturally more frequent here than under higher ground. Low ground also has the advantage that the water surface is closer to the land surface there than it is under the hills.

As the openings are less numerous at depth, the economic depth limit for limestone wells is usually set at 350 feet. If a well is dry at this depth, it is considered wise to abandon the hole, and drill another, unless there is other evidence that openings are likely to be found at a greater depth.

WELL DEVELOPMENT

Well development is that work which is done on a well subsequent to drilling and before production. It is important that a well be properly develope in order that it may operate most efficiently, that is, so that it will yield the maximum amount of water with a minimum drawdown of water level.

The purpose of well development is to increase the premeability of the water-bearing material surrounding the well thereby making it easier for wate to flow into the well. Development methods differ according to the character o the water-bearing material. In unconsolidated materials, such as loose sands and gravels water moves through the voids between the individual grains. Development generally consists of removing the finer particles from the

ter-bearing sediments leaving a new mixture which has a higher porosity and meability than the natural materials. General practice is to set a well-screen t will allow the fine 70 percent of the water-bearing sediments to pass into well, retaining the coarse 30 percent fraction outside the screen as a natural vel pack. The most common method of accomplishing this is by surging. A ton or plunger, called a surge-block is operated up and down in the well casing. the downstroke, water is forced violently out through the screen into the mation; this action agitates the materials around the screen allowing the finer ticles to move toward the screen on the upstroke of the surge block when the ter is drawn back into the well. Repeated surging will eventually draw all of fine material within the area of influence of the surging action into the well, from ich it is removed by pumping or with a bailer. Wells may also be surged using npressed air, steam, or natural gas as the surging force. The principle is the ne as in the use of the surge block, but these methods are generally more ective because the well may be pumped with an air-lift device during the surging.

Other common methods of developing gravel wells are over-pumping and kwashing. These methods are not as effective as surging, but no special uipment is required so they find wide use. Over-pumping consists simply of nping the well at a higher discharge rate than that at which it will be pumped regular service. This creates a steeper hydraulic gradient toward the well een, and a corresponding higher velocity than will occur under normal pumping; a result some fine materials are drawn into the well. But over-pumping s not agitate the saturated materials; consequently it affects only fine ticles that are free to move.

Backwashing in its simplest form consists of alternately stopping and rting the pump to produce sudden changes in the pressure head in the well. is method produces some agitation of the surrounding sediments, but the fine terials are not as forcefully removed as by surging.

REDEVELOPMENT

To retain the original capacity of a well, it may be necessary to period- lly redevelop the water-bearing zone. Over a period of time, fine-grained terial from the surrounding formation moves toward the well and clogs the ces between the larger gravel fragments. Redevelopment in this case consists repeating the development techniques used in finishing the original well.

Under certain circumstances, it may be necessary to use different methods development after a well has been in service. A common cause of decreased ld of a gravel well is encrustation of mineral matter on the well screen and the rock particles around the screen. Encrustation is most severe in wells t pump hard water. The carbonates of calcium, magnesium, and less frequently n, are held in solution by carbon-dioxide gas dissolved in the water. The bon dioxide will be released from solution if there is sufficient difference in ssure head between the water in the well and the water in the formation. The

release of carbon dioxide results in precipitation of mineral salts at the point where the head loss is greatest--generally at the screen where the water ente the well. Encrustation is most effectively removed by chemical treatment, either with inhibited hydrochloric acid, or a strong detergent. The well is surged as part of the treatment and the combination of the solvent action of th solution and the mechanical effect of the surging will generally remove all so material from the affected area. Dry ice is also used to remove encrustatio The carbon-dioxide gas released by dry ice is alternately forced into the form and then allowed to escape through the casing resulting in a surging action in the well. The presence of the gas aids in the solution of the mineral encrusta so the effect of dry ice treatment is similar to, but not as forceful as, acidiz and surging. It should be added that a better solution to encrustation is to re the cause of the problem by reducing the head loss through the screen by decreasing the entrance velocity of the water into the well. This may be done b either reducing the pumping rate of the well, or by increasing the effective a of the screen openings.